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NOTES ON THE INCIDENCE AND EFFECT OF STERILITY AND OF CROSS-FERTILISATION IN THE INDIAN COTTONS

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NOTES ON THE INCIDENCE AND EFFECT OF STERILITY AND OF CROSS-FERTILISATION IN THE INDIAN COTTONS.

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THE subject of the economic significance of Natural crossing in India has been dealt with in a recent memoir* and it is, therefore, unnecessary to do more here than recapitulate in the briefest manner the reasons which necessitate, prior to any attempt at improvement in a crop, the determination of the extent of cross-fertilisation normally taking place.

The methods which can be adopted to procure improvement in a particular crop have been classified by Cook†, and in the choice of method the experimenter must be very largely guided by two considerations, the extent to which cross-fertilisation takes place under normal field conditions, and the degree of sterility which may result in plants subjected to artificial self-fertilisation carried out through a series of successive generations.

The ultimate aim of all scientific work on the agricultural crops is not only the production of a type suited to the particular conditions under which it will be grown and having a produce improved either in quality or quantity, but such production on a

* Memoirs, Dept. of Agr. in India, III, No. 6.
† U. S. Dept. of Agr., Bur. of Plant Industry, Bull. 146.

sufficiently large scale to admit of wide distribution. The work of improvement, therefore, falls into two sections—the production of such an improved type, or types, in a state of purity and the multiplication of these types when established, until a stage is reached when distribution may be attempted. On the extent to which natural cross-fertilisation is found to occur, will depend the precautionary measures which must be adopted to prevent a gradual deterioration of the crop after distribution has been commenced.

In the first stage the number of individuals handled will be limited, and it is possible to adopt artificial methods, by protection of the individual flowers or even of the whole plant, to prevent access to the flowers of foreign pollen of unknown origin. In this stage, if natural crossing is shown to occur, the determination of the limits to which continued self-fertilisation can be carried is of an importance greater than the determination of the extent of such crossing, for on this will depend the methods to be adopted in the isolation of improved types. In the second stage the numbers become too great for such artificial protection. The extent to which crossing takes place, then assumes a position of major importance, and, inasmuch as crossing between individuals of any particular type has no harmful influence, the determination of the conditions which render such crossing impossible is especially desirable.

That it is possible to determine with any mathematical precision the extent of cross-fertilisation taking place under certain conditions is hardly to be expected. The labour involved in attempting even a few such determinations would be considerable nor would it be safe to generalise from these, even when obtained, for in this particular it is quite possible that two similar types, or even individuals, might differ widely. For practical purposes a general idea of the extent of cross-fertilisation and the degree of sterility induced by repeated self-fertilisation is sufficient to indicate the methods and precautions it is necessary to adopt. The following observations on the Indian cottons are not, therefore, the outcome of a carefully planned series of experiments but rather

the collection of such observations as have a bearing on this subject, made during the course of a series of experiments having as their object the production of an improved cotton suited to the conditions of the United Provinces. As has been stated, they deal with two distinct phenomena, the occurrence of sterility, chiefly as the result of repeated self-fertilisation, and the frequency of crossing in nature, which two phenomena require separate treatment.

Sterility as the result of repeated self-fertilisation.

It is a matter of common knowledge that the extent of cross-fertilisation occurring in different plants in nature is most divergent. At one end of the series lie the dicœcious species, in which self-fertilisation is impossible and from which, through the various forms in which, by protandry, protogyny, and the various adaptations, such as dimorphy, self-fertilisation is injurious, it is possible to pass to the other extreme, represented by plants with cleistogamic flowers, where self-fertilisation is the rule. The facts first collected by Muller* and Darwin† and more recently by Knuth‡ are so well known that it is hardly necessary to make further reference to this general aspect of the subject. It is sufficient to note that the cotton flower exhibits none of those adaptations which would indicate that it is normally either cross, or self-fertilised. There is, therefore, no *a priori* reason for anticipating any marked degree of self-sterility, indication of which can only be obtained from direct observation. Difficulty here arises through the absence of any method for directly measuring the degree of self-sterility, for such sterility may take various forms. Thus the fruit of flowers fertilised by their own pollen may fail to set or, having set, may undergo partial development only and fail to ripen. They may, on the other hand, produce seed which, when sown, gives rise to plants which are completely, or partially, ste-

* The Fertilisation of Flowers, 1873.
† The Effects of Cross and Self-fertilisation, 1876.
‡ Hand-book of Flower Pollination.

rile or which exhibit a lack of vegetative vigour. The subject, therefore, may be best handled by tracing the progeny of individual plants through a series of generations.

Observations on the incidence of sterility.

Type 3.* *G. arboreum*, L. The *Nurma* cotton of Northern India. In 1906 three plants of this type were grown and from these seed was obtained by the simple process of bagging the flowers. Of seventeen flowers so bagged eight set and gave seed. Of the plants raised from this seed in 1907, twenty flowers were similarly bagged but of these three only set. Later in the season, therefore, a further series of six flowers, in which cross-fertilisation from sister plants was effected, was bagged and of these two set. Mainly owing to the fact that *Nurma* cotton is readily obtained in a state of purity as the result of its growth being confined to the neighbourhood of temples and at a distance from the ordinary field cotton, and also to the fact that it is a perennial and can be rattooned, no further attempt has been made to grow this type from seed derived from self-fertilised flowers. The numbers are small but, as far as they go, show a marked diminution in fertility as measured by the percentage of fruits which set in the second generation.

Type 9. A form of *G. neglectum*, Tod., with white flower and a leaf-factor $\rangle$3. A single plant culture of this type has been maintained since 1906. The original plant was then chosen on account of its prolific habit, the weight of bolls necessitating the use of artificial support. In this year fourteen flowers were protected and seed was obtained from seven of these. Of the offspring twenty-one flowers were similarly protected in the following year and of these nine only set. In 1908 some sixty plants were raised from the seed so obtained and of ten flowers protected not one set. In this case the carpels of the protected flowers did

* For the numbers here used to denote the types *cf.* Leake, Jour. of Genetics, I, pt. 3 (1911), and appendix to this note.

not undergo even the partial development that so frequently takes place, but the flower fell immediately and *in toto* from the base of the peduncle. An examination of the flowers of this generation disclosed a condition of almost complete sterility of the stamens which were white and shrivelled and rarely liberated pollen. Seven flowers were subsequently fertilised with the pollen gathered from sister plants and of these seven three set and ripened fruit. No detailed note has been kept of the subsequent (1909) generation but thirty-two flowers were protected and from these one hundred and twenty-three seeds (representing some fifteen bolls) were obtained. The sterile condition of the anthers, though present, was not such a marked feature of this generation. In 1910 a series consisting of forty plants was covered by a single net and has yielded seven and a half oz. seed.

In this case continued self-fertilisation appears to have brought about a marked degree of sterility which is, further, associated with the abortion, or incomplete development, of the stamens; also fertility has to some degree been restored by crossing between sister plants, but this restoration is partial only and the plants now representing this type exhibit none of that fertility which characterised the original plant first selected in 1906.

Type 6. A form of *G. neglectum*, Tod., with white flower and a leaf-factor < 2. Two single plant cultures of this type have been under continuous cultivation since 1906. Of the original plants ten and twenty flowers were protected and from these six and eleven bolls respectively set. In 1907 eleven and ten fruits set from twenty-two and twenty flowers similarly protected. In 1908 the sterile condition of the anthers above noted as occurring in Type 9 made its appearance but was less defined in the first, than in the second, culture. In the latter the condition was as marked as in Type 9. In the former culture, therefore, flowers, eighteen in number, were protected and of these nine set, while in the latter a single flower only was protected and immediately fell. In this case sixteen flowers were fertilised with pollen from sister plants

and, as a result, nine fruits were obtained. Of 1909 full details are again lacking, but from fifty-four flowers of the first culture bagged ninety-one seeds (representing some eleven bolls) only were obtained, while of the second culture, in which crossing had taken place during the previous year, ten protected bolls gave sixty-nine seeds (representing some eight bolls). In both cultures in this year a further series of fertilisations was carried out in which flowers were fertilised by hand with (1) the pollen of a second flower of the same plant, or (2) the pollen of a sister plant.

In the former culture ten and nine fruits set out of twelve and thirteen flowers respectively, while in the latter three fruits set out of the seven flowers fertilised with pollen of the same plant, while all (three) set when pollen of a different plant was used. In 1910 the combined offspring of the second culture numbering forty-five plants have been protected by a single net and given eleven and three quarters oz. seed.

In this type, though both cultures exhibit the phenomenon of abortion to some extent, there appear indications of the existence of an individual difference in the degree of sterility induced by self-fertilisation. How far self-sterility in the cottons is a function of the individual can, however, only be determined by a definite series of experiments designed to elucidate the particular point. Sufficient has here been noted for the present purpose which is to show that it occurs to such an extent that it cannot be ignored if pure races are to be raised from single plant cultures without a loss of fertility.

These results are collated in Table I.

Other forms of sterility.

So far sterility has only been considered in its relation to pure types and there remains the case of the offspring of a cross. This forms a subject of considerable difficulty since, superimposed upon the sterility above dealt with, there may also exist that which arises as the result of specific or racial diversity. It is well known that the power to effect cross-fertilisation is strictly limited, that

while such fertilisation is readily effected between certain plants and will give rise to fertile progeny, in other cases it is totally unproductive. Between these extremes lie those cases in which offspring is produced but in which such offspring is wholly or partially sterile.

Observations as to this latter form of sterility are not numerous. As far as they go, however, these tend to show that the Indian forms of cotton constitute a fairly definite group, the members of which show complete sterility when crossed with other forms of Gossypia. Gammie* records failure in his attempts to cross *G. hirsutum*, Mill., by the Indian cottons and the authors have similarly been met by a like failure. Among the Indian cottons, however, there appears to exist considerable divergence in the degree of fertility when they are crossed *inter se*. In some cases no diminution of fertility results, while in others various degrees of sterility are developed. As examples of the former case may be cited all crosses between Types 5-9 (*G. neglectum*, Tod., and *G. roseum*, Tod.) ; between Type 3 (*G. arboreum*, Linn.) and Type 4 (*G. indicum*, Lamk.), Types 5-9, Type 10 (*G. sanguineum*, Hassk.) and Type 11 (*G. cernum*, Tod.) and also between Type 4 and Types 5-9. In all these cases crosses have been effected and fully fertile offspring raised. Crosses have also been made between Type 3 and Type 1 (*G. obtusifolium* Roxb.) and Type 2 (*G. herbaceum*, Linn.), and these offspring are apparently fully fertile. Owing, however, to the late flowering habit of these types considerable difficulty attaches to the cultivation of these crosses in Northern India and they were discarded after the F_2 generation.

Crosses between Type 2 and the sympodial forms, of which Types 4, 5 and 9 were selected for the purpose, showed a considerable degree of sterility. This is indicated by a comparison of the figures given in Table II. In the second generation of the cross between Types 2 and 4 the percentage of bolls which set was reduced to less than 11 and the plants of this generation set practically no

* The Indian Cottons, 1905.

seed. For this reason Type 2 has not been used in the experiments conducted with the object of raising races of improved cotton suitable to the United Provinces.

One further type of cotton, *G. Stocksii*, M. Mast., is found in India and has formed the basis of some experiment. Seed of this type was obtained from the wild plants found on the limestone hills around Karachi. Both *G. arboreum* and *G. herbaceum* have been crossed with this plant and in both cases seed was obtained. This seed germinated and gave rise to plants which have been grown for three seasons. They remained diminutive, however, and have died without producing any flowers, though the parent plants have flowered freely and subsequent generations have been raised from their seed. From this condition of complete sterility in the F_1 generation it is but a short step to those cases in which attempts to produce a cross have resulted in complete failure.

G. Stocksii, though found wild in India, differs in a remarkable degree from the other members of the Asiatic (Indian) group of Cottons (subsectio Indica) as defined by Todaro.* By Watt† it is placed in a different section of the genus and the correctness of its inclusion in the Genus Gossypium even has been called in question.‡ In this connection it is of some interest to find that, as far as experiments have been made, this plant forms the single instance of a cross between a member of the Asiatic series and other forms of cottons being produced.

The determination of the degree of sterility which may arise in the progeny of crosses such as have been considered above is a still more complex matter. Numerous cultures, involving several thousand individuals, have been carried by successive selfing as far as the F_4 generation. Certain of the plants of this generation display a very marked fertility and undiminished vigour. Others, on the other hand, appear to be nearly sterile though a case of complete sterility has not been observed. The cause of this divergence

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* Osser. sui Cotoni, 1863.

† Wild and Cultivated Cottons of the World.

‡ Watt l. c. p. 56.

between plants of similar parentage remains obscure, and it has been found impossible to predict its occurrence in any particular plant or group of plants, and it appears to be a phenomenon quite distinct from the two forms of sterility above dealt with. The solution of the causes leading up to this fortuitous sterility is a matter which has a considerable practical bearing on the raising of improved races. That there lies here a field for cytological work* appears undoubted but hitherto the opportunity for conducting such work with the material to hand has been lacking.

The frequency of cross-fertilisation in the field.

(*a*) *The structure of the flower.*

The transference of pollen from one flower to another is, in general, effected by one of the two agencies, wind or insects and the flower is, further, frequently adapted to secure the services of a particular agent. Considered from this aspect the cotton flower shows but little adaptation. The petals are as a rule conspicuous and expand widely, and the pollen grains are large and round and covered with short papillæ. Nectaries occur at the base of the petals and the honey secreted by them accumulates outside the petals in the cup formed by the gamosepalous calyx and access to this honey is only obtained through the narrow slit-like passages between the five petals. The above structural peculiarities are such as are commonly associated with the visits of insects, and there is little doubt that whatever cross-fertilisation takes place is the result of such visits. On the other hand, the rupture of the anthers and consequent liberation of pollen synchronise very closely with the maturation of the stigma. During the cotton season the petals expand about 8 A.M. and within thirty minutes of this expansion the pollen is liberated and the stigma has become receptive. The pollen is at first sticky but soon becomes dry and powdery and falls on the slightest agitation of the flower. Though the position of the flower is by no means constant it is, perhaps, most commonly horizontal or pendent. The

* Cannon, Bull. Torrey Bot. Club, XXX, 1903.

flower, therefore, undoubtedly becomes self-fertilised within a very short period after the pollen is liberated. Moreover, the flower is ephemeral and the growth of the pollen tube is consequently rapid. Cross-fertilisation, therefore, is only likely to occur if foreign pollen reaches the stigma within the very limited period which elapses between the opening of the flower and the act of self-fertilisation. The brevity of this period suggests that cross-fertilisation will not be so common as the structural consideration would indicate.

(*b*) *The condition of the cotton crop.*

Indirect evidence as to the occurrence of cross-fertilisation is to be found in the condition of the cotton crop as usually cultivated. In Northern India the only types which are to any extent cultivated on a considerable scale are those falling under the designation of *G. neglectum* and *G. roseum* of Todaro and, in the Eastern districts of the United Provinces and Bengal, the types which have been grouped under *G. intermedium*, Tod. In both cases the field crop includes a most diverse assemblage of forms which defy classification until single plant cultures are grown under conditions which exclude cross-fertilisation. It is then seen that the apparently wide diversity of form resolves itself into a comparatively few types with which are mingled numerous intermediate forms which, when subjected to such rigid experiment, are found to be impure. The cause of the original mixing of types is, and will, no doubt, remain obscure, but the general occurrence of such impure forms must constitute a strong argument for the occurrence of cross-fertilisation.

For other parts of India, and especially the Deccan, Fletcher* has shown that the crop consists of a large mixture of types. In a few cases only, those of Broach (Type 2) and Dharwar Saw-ginned cotton (a form of *G. hirsutum*), is the crop pure. In the former case purity is maintained by the different flowering period of the crop while the latter form, as has been stated, does not cross with the Indian Cottons. Here the original cause of the mixing of types is no doubt in large measure due to the economic conditions mentioned;

* Agl. Journal of India, I, 1906, p. 470.

but it is a significant fact that the only types grown pure are those whose natural habit helps to preclude the occurrence of cross-fertilisation.

(*c*) *Previous observations on the subject.*

From time to time the most divergent views on the extent to which cross-fertilisation takes place in the field have been advanced. At one extreme lie the views of Gammie who records* a series of observations which led him to conclude that "Indian Cottons are normally self-fertilised." At the other Cook† considers that it occurs with a frequency that might render it possible to produce on a commercial scale F_1 crosses by the simple process of growing the two kinds it is desired to cross in alternate lines. The crop raised from the seed so obtained will contain so many crosses that the pure parents may be rogued out without excessive thinning of the crop. It will be noted that these extreme opinions are based on observation of very different types growing in very distant localities. There is, therefore, no inherent difficulty in believing that both opinions may be correct for the particular types and for the particular area in which the observations were made. The structural similarity of the flower in all the types is, however, very great and on *a priori* grounds, therefore, it would seem probable that such differences as occur would be slight. It has been shown above that such crossing as takes place is caused by insect visitors and any divergence found in the amount which occurs is to be sought, therefore, not in the structural peculiarity of the flower but in the climatic conditions which obtain when the cotton plant is in flower and which directly affect the abundance or paucity of insect life.

Of the expressed views which lie between these two extremes those which are the result of observations made in India on the Indian cottons are most germane to the present question and may be dealt with first. It is impossible here to detail all the earlier observations on the subject. Reference to these is to be found in Watt's

* The Indian Cottons, 1905.

† U. S. Dept. of Agr. Bureau Plant Industry Bull, 147.

article on Gossypium.* From their consideration as well as from the results of much personal observation, he has formed the opinion, expressed repeatedly throughout the article, that hybridisation has played a large part in the history of the cotton plant of India and even that many of the widely cultivated forms owe their origin to this process. Later, in a more recent work,† he expresses the same view.

Middleton has subjected the Indian cottons to a detailed examination covering a number of years. In the record of his results‡ he gives no definite expression of opinion on the extent of cross-fertilisation, but it is clear that he believes it to occur with a frequency which makes the origin of many cultivated races by this means possible. Thus of the Nadam cotton of Madras he writes, "I suppose Nadam to be "a hybrid with a strong strain of *G. arboreum*, the other parent being *G. herbaceum* or *G. indicum*," and the possibility of an origin of numerous other cultivated races by similar means is indicated.

Fyson,§ as a result of a series of experiments, was led to believe that a certain amount of natural crossing occurs. Thus he found the white-flowered parents from a cross between white-and yellow-flowered forms gave a few yellow-flowered offspring (two cases of forty-three observed). The occurrence of these he attributes to vicinism.

Burkill|| has approached the subject from a different standpoint, having collected observations on the insects visiting the cotton flower. In the earlier note are recorded observations from Behar and in the later those made in Berar and Central India. He sums up the observations made in the former case by saying "It seems, "then, that insects such as I observed visiting the flowers in Behar "do produce an effect; but it is an extremely small one indeed— "merely a hybrid plant here and a hybrid plant there."

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* Dict. of the Economic Produc'a of India, esp. p. 39-42.

† The wild and cultivated cottons of the world, 1907, see esp. p. 90.

‡ Agricultural Ledger II, 1895, No. 8.

§ Memoirs of the Dept. of Agr. in India, Bot. Series II, 1908, No. 6.

|| Jour. As. Soc. Bengal III, 1907, p. 517 and VI, 1910, p. 101.

A number of observations of a series of Indian types growing at the Royal Botanical Garden, Palermo, has also been made by Todaro.* As this work is not readily accessible a translation of his remarks may here be given.

"*G. herbaceum* Linn. in this cultivation of 1877 preserved "its character unchanged, as in all preceding years.

"In the different qualities of *G. wightianum* sown this year in "greater proportions, important phenomena were to be seen, which "show that this Indian species crosses very easily with the other "species proper to the Old World; for it is sometimes crossed "with our *G. neglectum* and sometimes with *G. herbaceum var. micro-* "*carpum*, its hybrids assuming intermediate forms which link one "to the other; but on repeating the culture of these hybrids, "which are all fertile, we get plants nearer to the types, and "in the second year some exhibit all the specific characters either "of *G. wightianum* or of *G. neglectum*, while cultivated separately "and at a great distance apart, they preserve their characters "intact.

"*G. herbaceum var. microcarpum* can fertilise *G. wightianum* "and *G. neglectum*, but it is never fertilised by them; like the species, "however, the seeds of the hybrid constantly reproduce the same "plant. When *G. herbaceum* is repeatedly grown in poor ground "without irrigation, the capsules and leaves become smaller, the "plant is less branched, but the size of the flower and the shape "and divisions of the bracts do not vary; this is not the case "with *G. wightianum* which is as easily fertilized by *G. neglectum* "as by *G. herbaceum var. microcarpum;* the colour and size of the "flower do not change, nor does the capsule acquire the dimen- "sions of those of *G. herbaceum;* and we never find in its bracts "the incisions and other characters which distinguish the species "with which it has been crossed.

"In these hybrids it is nearly always *G. wightianum* which "fertilizes *G. neglectum;* the plants obtained resemble *G.* "*wightianum* in the characters of their leaves; and in the second

* Rev. Cult. dei cotoni, p. 48, 1878.

" generation, as well as more rarely in the first, there is a marked " reversion to *G. neglectum;* while a reversion to a pure " *wightianum* happens less frequently.

" Here it happens that in the large plantations of India there " exist intermediate forms which have made the English botanists, " who consider these hybrid forms simply as varieties of one " species, believe that between *G. arboreum* Linn. and *G. herbaceum* " there are so many links that they must constitute a single " species.

" The species cultivated in the Old World have no agricultural " importance ; their capsules are always small, the wool is short and " rather coarse compared with that of the American kinds, and " cultivation has hitherto been unable to increase the dimensions of " their capsules, or to improve the cotton."

The occurrence of cross-fertilisation of cotton outside India has also been frequently noted. In America the belief in its occurrence though of limited extent, appears to be very general.

The opinions of several workers in America are recorded by Middleton.* Webber† states that " In several instances varieties " have been grown in single rows with other varieties all round " them of such a kind that crossing, where it occurred, could be " easily detected in the progeny. Plants grown from seed matured " under such circumstances show but few crosses, indicating " that the majority must have been self-fertilised. Judging from " the observations thus far made, it would seem that ordinarily " only 5-10 per cent. of the seeds are normally cross fecundated."

The same author has also dealt with the effects of the occurrence of such cross-fertilisation in its bearing on the methods of selection.‡

The work of Cook has already been referred to (p. 11). His observations on certain Egyptian cottons grown in America point to the hybrid nature of some of the plants.§

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* Loc. cit., p. 24.

† U. S. Dept. of Agr. Year-book, 1902, p. 370.

‡ U. S. Dept. of Agr. Year-book, 1898, p. 364 et seq.

§ U. S. Dept. of Agr., Bur. of Plant Ind., Bull. 156, p. 20.

In Egypt Foaden* has drawn attention to the difficulty attaching to the complete eradication of the inferior Hindi cotton by any method of roguing. Balls† has noted the mixed nature of the crop and, from his observations, calculates‡ that "all the kinds of cotton which I have grown in Egypt are liable to *at least* five per cent. of cross-fertilisation per annum.§

Observations on the incidence and extent of Cross-fertilization in the field.

This subject has been dealt with very briefly in an earlier note‖ in which a few early observations on the occurrence of natural cross-fertilisation in Northern India were described. Two instances alone were described in any detail and since these have formed the subject of further experiment, they may be treated more fully here.

In the first case, a single plant of a number belonging to the forms included under the term *G. neglectum* Tod., which were self-fertilised, gave offspring whose several leaf factors ranged over the entire scale while the offspring of the remainder were pure to this character. Eleven of the offspring of this plant, having leaf factors of different values, were again self-fertilised and in the subsequent generation it was found that those plants having a factor $\langle$ 2 or $\rangle$ 3 bred pure, while the intermediate forms gave rise to a series of plants with leaf-factors of most divergent values. The results are given in Table III, section (*a*). If this is compared with section (*b*) of that table, which gives the results obtained from a cross purposely effected between two types known to be pure, the similarity will strongly suggest that the plant in question was the result of a cross between a broad lobed, and a narrow lobed,

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* Year-book Khed. Agr. Socy., 1905.

† Year-book Khed. Agr. Socy., 1906.

‡ Jour. Agr. Sci. II, 1908, p. 353.

§ For further reference to this subject, see also Aliotta, Riv. Crit. del Genere Gossypium. Unfortunately opportunity for consulting this work has hitherto been wanting.

‖ Jour. As. Socy. Bengal IV, 1908, p. 13.

parent, though no indication of the remoteness of that cross is obtainable.

The second case is that of two plants raised from a packet of seed supplied as pure Nurma (*G. arboreum* Linn.). These differed from the type in being more vigorous, in having an intermediate leaf factor and the red colour of the plant slightly developed (as far as the veins). From one of these plants seed was raised and thirty plants were obtained. These thirty plants were classified into three groups.

(*a*) Foliage and flower deep red 9
(*b*) Foliage with red to veins, flower red on yellow .. 13
(*c*) Foliage green, flower yellow 8

Of these groups four, eight and three plants, respectively, were self-fertilised and a subsequent generation raised from the seed so obtained. They may be considered separately.

(*a*) From the four plants of this group seventy-one were raised and were found to be pure as regards the character under consideration and in this respect they appeared typical of the type *G. arboreum*.

(*b*) Of the eight plants six gave the three forms (*a*), (*b*) and (*c*) only, in number thirty-five, sixty-four and fifty-five respectively; one of the remainder gave in addition offspring with the flowers red on white, while the last gave yet another additional form with white flowers. The numbers for these two plants are given below :—

		(1)	(2)
(1) Foliage full red ...	flower full red	...	3
(2) Foliage with colour to veins ...	flower red on yellow	10	10
(3) Foliage full red ...	flower pink	4	4
(4) Foliage with colour to veins ...	flower pink	5	
(5) Foliage green ...	flower yellow	8	6
(6) Foliage green ...	flower white	...	1

(*c*) Of the three plants with yellow flowers two have given thirty-seven offspring with yellow flowers only, while the third has given thirty-nine plants with yellow, and nine with white flowers.

Of the plants thus obtained in the series given under (*b*) a subsequent generation has been raised from the three with the foliage

bearing the red colour in the veins and pink flowers and from the single plant with a white flower. All the three former have given the two forms with pink flowers and also white-flowered plants, while the white-flowered plant has given whites only. The similarity between the behaviour of this series and that of the cross between Type 3 and Type 9 (red-flowered *G. arboreum* and a white-flowered *G. neglectum*) is so striking that it is impossible to avoid the conclusion that the original plant was derived from a cross between two plants having similar characters. It is needless to follow this series through the details of the leaf factor. That of the original plant was intermediate and the subsequent generations have split up in a manner similar in every respect to the case noted above. From its occurrence in a packet of seed of *G. arboreum*, it is probable that this plant was a first cross and it may safely be concluded that one parent was *G. arboreum* while the other must have been a white-flowered plant with leaf factor $\left\langle \right.$ 2—probably a plant of Type 6.

It is unnecessary to enter in detail into each of the numerous cases of impurity which have been observed to arise in like manner in cultures raised from the seed of naturally fertilised fruits. In the few cases in which they have been investigated they have been proved by the character of their progeny to be the result of cross-fertilisation. For the present purpose it will be sufficient to describe the three series of observations which most clearly illustrate the point.

(1) Type 2 (*G. herbaceum*, *Linn.*) has been grown for a series of years ; during the first two seasons only seed from protected flowers was sown and the culture so produced proved to be pure. In 1907 this seed was limited in amount, and a second culture was, therefore, raised in 1908 from seed of the same parents, but gathered from unprotected flowers. Of these two cultures the former consisted of twenty-one plants all of which were true to type, while of the latter eleven plants were pure and three undoubtedly crosses. In two of these three there was a marked development of sympodial secondary branches and a consequently shortened vegetative period, while in the third case the leaf factor was also intermediate(2·5)

(2) In 1906 the seed of sixty plants was gathered from a field crop of *G. neglectum* Tod. and *G. roseum* Tod. and sown in separate lots in the following year. These included the types (5—9) with both "broad-" and "narrow-" lobed leaves and with yellow and white flowers. The observations on the flower colour of this series are given in Table IV. Owing to the fact that in these types yellow is completely dominant to white it is impossible to detect crosses between yellow and white-flowered plants in the progeny of the yellow forms. Here it is only possible to conclude that the thirty-four plants selected were pure yellows. The white-flowered plants have, however, given seven yellow offspring, and these seven are undoubtedly crosses. Accurate information concerning the leaf form is not available since no determinations of leaf factor were made in this series. A record has, however, been kept in which three groups, broad-lobed, narrow-lobed, and intermediate, have been distinguished. These are tabulated in the second section of Table IV. From this it will be seen that thirty-eight plants out of the sixty gave offspring without impurity; that twelve were themselves pure, but that among two hundred and seventy-five offspring occurred twenty-eight plants which showed clear indications of being the result of a cross, and that the remaining ten plants were themselves impure. Of these last it is only necessary to remark on the paucity of intermediates. At the time these observations were made the leaf factor had not been identified and no means of accurately recognising the limits of the "broad-" and "narrow-" lobed types had been found. There is little doubt, therefore, that many of the forms which, though intermediate in reality, approached one or other extreme, were included among the extreme forms and consequently it is impossible to draw any conclusion from the marked divergence from the normal in the numerical proportion of the groups.

(3) In the cotton season of 1909 considerable damage resulted from the ravages of the boll worm, numbers of the self-fertilised bolls were attacked, and it was feared that loss of promising types might result owing to the reduction of the quantity of seed harvested. A further supply of seed was, therefore, gathered from the same

plants and sown in 1910 as a collateral series which only differed from the first in the one feature that the flowers had not in this case been protected. A third series was also grown from seed gathered at the end of the hot weather, 1910, from the same parents which had been transplanted and cut back early in the year. The second and third series are those termed respectively "early" and "late" series in Table V. The observations collated in this Table are limited to a record of the red sap colour of the vegetative parts of the plants and of the flower colour. In the first series, from self-fertilised seed, as in previous years, plants having the sap colour spreading to the lamina have given pure red offspring only and, similarly, plants in which the red colour is absent (foliage colourless or green) have given colourless offspring only. In both the naturally fertilised series, as Table V shows, a considerable number of impure forms have occurred. Further the colour of these aberrant forms is, with a single exception (not included in the above table as it appears to be almost certainly the result of accidental mixing of seed), the intermediate form, with the red colour only partially developed, which is invariably produced when a pure red plant is crossed by one in which the colour is absent. To pass to the flower colour, it has been shown by numerous experiments that when full precautions have been taken a white-flowered plant invariably breeds pure to this character, but in these two series a certain number of yellows have occurred which can only be the result of natural crossing.

Confirmation, if such were needed, could be obtained from the leaf factor, but in view of their somewhat tedious character, the need did not appear to justify the expenditure of much time on the determinations, which were only made in the case of those plants used as parents and whose purity it was desirable to ascertain as far as possible. A superficial observation, however, was sufficient to indicate that numerous intermediate forms occurred among the offspring of plants which were pure in their leaf character.

The difference in the percentage of impurity as given in Table V for the two series is a matter of some interest. In one case only does that figure for the late series exceed that for the early series,

and in this the number of individuals is too small to admit of much weight being attached to a percentage figure derived from their use. In all other cases the number of crosses occurring in the early series is proportionately high, for, while the combined percentage is approximately eleven for the "early" series, that for the "late" series is 3·5. Now the flowers from which the seed giving the "early" series was derived were open at the end of the rains, a season when the atmosphere is still moist and the temperature not excessive. The late series, however, is derived from fruit set during the intensely hot and dry summer months of April and May. In the former case the abundant insect life of the rains is still present, while in the latter the conditions are such as to reduce this to its minimum. It is reasonable, therefore, to conclude that there exists a close interrelation between the abundance of insect life and the amount of cross-fertilisation and the observation adds weight to the opinion already expressed (p. 47) that the divergent views on the occurrence and extent of cross-fertilisation are to be traced to the difference in climatic condition.

Hitherto the extent to which cross-fertilisation occurs has been considered from the general aspect only. There remains the further problem of the distance at which it may occur. This problem is far more complex, but is also one of great practical importance since the greater the distance at which cottons are found to influence each other, or, in other words, the greater the distance to which pollen is found to be carried, the more intricate must be the precautionary measures taken for extending the culture of new kinds to prevent the swamping effect of accidental cross-fertilisation. In this connection Webber* states that absolute isolation would require a separation of from 5—10 miles, but that practical isolation may be procured at a distance of a quarter to half a mile. If this proves to be the case with the Indian Cottons the difficulties accompanying any multiplication of a pure race on to a commercial scale will be considerable.

* U. S. Dept. of Agr. Year-book, 1902, p. 370.

Opportunity for collecting evidence on this head has been limited, but it is satisfactory to find that, to prevent cross-fertilisation as far as it is possible to draw any conclusion, such distances appear to be unnecessary. Such observations as have been obtained are derived from the 1910 series (early) grown from naturally fertilised seed. In this series, using the red sap, and the flower colour as distinctive characters, the number and character of the crosses occurring in the offspring of each individual separately has been recorded, and the position of each parent plant in the field then traced back and a note made of its distance from the nearest plant capable of giving the particular cross observed. Such details have been obtained for some eighty plants and their respective offspring and tabulated in Table VI while the method is illustrated in Diagrams 1—4.

In the field the plants were ranged in lines 3ft. apart with a distance of 2ft. 6in. between the plants in a single line. Each plant, therefore, is surrounded by eight plants, two at a distance of 2ft. 6in., two at 3ft. and four at a distance approximately 3ft. 10in. These eight plants form an inner circle of neighbours and their branches may intermingle with those of the central plant. In no other case will such intermingling occur though, if the intervening plant dies, a short distance only will separate the plant from plants separated by a distance of 5ft. in one direction or 6ft. in the other.

Table VI may, therefore, be considered as falling into 3 sections: —the first includes all those plants situated within four feet of each other; the second, those separated by a distance greater than four feet but less than 10 feet; and the third, those separated by 10 feet or more. In the first case, as the table shows, crossing occurs with considerable frequency and the same remark applies to the second group. In the latter case, however, with one exception (Diagram 3), the intervening plants have died, and there is, therefore, direct access from one plant to the other. In the third group, if the offspring of a single plant are excluded, no crossing has taken place. In the exceptional case (Diagram 2) distinction can be drawn between the three crosses. In two of them, in addition to the yellow

colour introduced into the flower, the foliage shows the impure condition with the red colour as far as the veins only. These two crosses must have been produced by a cross from a yellow or impure red, parent and the nearest plant of either kind is one with a yellow flower situated at a distance of 10ft. In the third case the full red foliage colour is retained and the cross is indicated by the introduction of the yellow only. This can only be effected by a pure, or by an impure, red. The nearest plant of either kind is a pure red situated at a distance of 13ft.

In Diagram I are given a group of eight plants with their neighbours; though each of the eight is situated within 2ft. 6ins. of at least one plant the cross from which would be recognisable in the offspring, yet in four out of the eight cases no such cross has occurred. The facts here detailed are insufficient to justify any absolute statement, but clearly point to the conclusion that, for practical purposes, there is no objection to cultivating different races in adjoining plots provided the two lines bordering the second race are discarded for the purposes of seed supply. Additional security, and one which might render even this precaution unnecessary, may perhaps be obtained by the separation of two kinds with one or two lines of a crop which flowers freely during the cotton season and will grow under the same conditions as cotton. For this purpose the Indian Sann (*Hibiscus cannabinus*) or *H. Sabdariffa* naturally suggest themselves.

The insects visiting the cotton flower.

It is not proposed to devote more than a cursory glance to this aspect of the subject which, as far as India is concerned, has been investigated in some detail by Burkill.* The diversity of the insect flora in the various cotton tracts of the world prevents the deduction of general conclusions from observations in one area. Such conclusions must be, to a greater or less extent, of local application only. Certain points in this local aspect may, however, be referred to as having some bearing on the experiments above noted.

* Loc. cit.

From the observations just recorded it would appear that in the United Provinces such cross-fertilisation as occurs is the work of some insect with a limited range of flight. Of the two insects most commonly observed at the cotton flower one is a small bee *Apis florea* Fabr.* Towards sunset this bee is to be found in the partially withered flowers, in which it appears to spend the night, to issue on the following morning densely coated with pollen. It is possible that some of this pollen may still be adhering when the flowers first open and undoubtedly pollen then deposited on the stigma is most likely to cause fertilisation, for the anthers are at the time still complete. On the other hand, the period between dawn and the opening of the flower is considerable, and in this period the insect which is strong on the wing would have covered a considerable distance. If the conclusions drawn as to the distance at which cross-fertilisation takes place be correct, it would appear more probable that, by the time the flower opens the insects have freed themselves from adherent pollen and therefore are rarely, or never, the agents of cross-fertilisation.

The second insect commonly met with on the cotton flower is a small beetle, *Carpophilus dimidiatus* Fabr. The range of this beetle is undoubtedly limited and frequently numbers are to be found crawling inside a single flower. In their actions they may be described as clumsy, frequently falling from one portion of the flower to another and in so doing they become densely coated with pollen. They may, moreover, frequently be seen in the morning, having left the withered flowers of the day before, entering the unopened or opening flower by forcing their way between the spirally wound petals. Though a great deal of the pollen is, no doubt, dislodged during the process there seems every possibility that a certain amount may be still adhering when the insect gains the interior of the flower, and if it is then deposited on the stigma, cross-fertilisation is almost sure to occur.

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* For the identification of these insects I am indebted to Mr. H. Maxwell-Lefroy, Imperial Entomologist.

Concluding observations.

Sufficient has here been shown to warrant two main conclusions, firstly, that a considerable degree of sterility results from self-fertilisation repeated through a number of successive generations; and, secondly, that cross-fertilisation takes place to a considerable extent, though the greater portion of this is limited to neighbouring plants.

The practical bearing of these considerations is of some importance. In the early stages of experimental work, when individual plants are under examination, it is necessary to guard against the effects of cross-fertilisation by protecting the flowers. By so doing, however, considerable danger is incurred of the loss of vigour and even of the loss of the race through sterility. While, therefore, it is not impossible to raise and carry on single plant cultures—and in fact, such has actually been accomplished in the case of most of the types,— such cultures are likely to be of slight practical value. As far as possible, therefore, it appears advisable to avoid such cultures and to rely for purity on the careful selection, combined with roguing, among such plants as are least likely to have been crossed. For this purpose the types must be grown in numbers sufficient to give a fair body of individuals separated by at least 10ft. *and* by intervening plants from individuals of a different type. In this manner a race of Type 7 exhibiting the full vigour of the original stock has been raised. A further method has been attempted in which a set of 40-50 plants of one type have been enclosed by a single net. It is here impossible to exclude all insects, but the number passing through the net is very small, while those enclosed are only able to effect cross-fertilisation between individuals of the same type. The effectiveness of the method still remains to be proved.

It has been shown that, in exceptional cases only, is the cotton crop in any part of India pure and the same may be said to be the case in other countries also. A series of cottons grown from seed from China and Persia have been found to consist of a number of

forms. Balls,* as noted above, has drawn attention to the mixed nature of the cotton crop in Egypt, while the history of the origin of the named varieties of American cottons as far as this is known, sufficiently indicates that in America, too, a similar condition is to be found.† Such a mixed crop no doubt adjusts itself to its surroundings and, under certain constant conditions, will maintain a definite proportion between the various constituents and even in certain cases, appear to be pure. When such a crop is grown under different conditions it is highly improbable that the proportion between the various constituents will remain unaltered. The new conditions will favour one or other of the component types which will, in a short time, become the dominant element of the crop. It will not be inappropriate here to refer to the example afforded by wheat. There have from time to time been recorded frequent instances of the conversion of red, to white, wheat and of bearded to beardless as the result of ' degeneration ' consequent on change of environment. Such cases, when put to the test, are invariably found to be referable to the occurrence of an, at first, inappreciable admixture of the ' degenerate ' form which, when grown under favourable conditions, increases rapidly and may even ultimately swamp the original kind. If such cases are possible with wheats, in which in Europe, where such instances of ' degeneration ' have been recorded, cross-fertilisation is of the rarest occurrence, the danger of this ' degeneration ' occurring in a crop like cotton in which cross-fertilisation has also to be taken into consideration must be far from inappreciable. Instances have been actually recorded in the case of maize and the true explanation of such phenomena with especial reference to these two instances is given by De Vries‡ with much directness. Under these circumstances it appears possible to carry out experiments on the effect of change or environment with pure cultures only, and preferably, with single plant cultures, if such be obtainable. Unless this precaution is

* Year-book Khed. Agr. Socy., 1906.
† The Cotton Plant, U. S. Dept. of Agr., Exp. Sta., Bull. 33.
‡ Die Mutations Theorie I s. 10, p. 67.

taken the diversity found may in reality only be a manifestation dependent on the occurrence of a small percentage of impurities.*

From very early times repeated efforts have been made to acclimatise various exotic cottons in India. In 1829 a farm was started at Akra for the purpose for which seed was obtained from America, though even before this date importations of seed had been made.† The only trace now to be found of the labour of generations in Northern India is in stray plants and, here and there, a stray field of the American type, the latter either the result of the most recent effort of the Department or of the enterprise of individual land-holders. In the rest of India the result is hardly different, and though in certain areas, as Dharwar, the type has become permanently established, it may be said in general terms that the record of acclimatization is one of failure. That such failure is due to imperfect cultivation may, in part, be true, but it is improbable that this is more than an indirect cause. It is only necessary to consider the early history of such importations to see that, for a short period, the crop is grown successfully and yields freely, and that sanguine hopes are built on the early years of experiment. It is impossible to read accounts of the earlier importations, such as are contained in Royle's Cotton Culture, in the Reports of the Cotton Commissioner and in the Journal of the Agri-Horticultural Society of India without being struck by this fact. The crop at first maintains its standard and subsequently undergoes a more or less rapid degeneration. The similarity between this and the cases of 'degeneration' in wheat is striking, and suggests the possibility of a like cause here.

The American forms of cotton in commerce have been raised to a large extent by selection. By such process the general standard in productivity, in length of lint, or in other desirable characters is raised to a high level, but the less desirable types are not completely eliminated. The improved plant is adapted to the conditions of the American cotton field with its highly developed

* Cf. Cook U. S. Dept. Agr. Bur. Plant Industry, Bull. 156.

† The earlier experiments in this direction are recorded in Dr. Royle's Culture and Commerce of Cotton in India.

system of cultivation, and may perhaps of itself be able to maintain its dominant position in the mixture of which the crop in reality consists. Frequently, however, this is not the case, and even in its country of origin the dominant position is only maintained by a continuous system of roguing. Such a commercial variety is in the optimum condition to exhibit this phenomenon of 'degeneration' when grown under changed conditions, and when these conditions include, in addition to climatic differences, a less careful cultivation and cessation of the process of roguing, it is hardly a matter for surprise that some of the hardier forms contained in the mixture should assert themselves to the partial or complete exclusion of the finer ones.

The process of acclimatization has consequently been marked in most, if not in all, cases by a deterioration of the produce which has been in many cases attributed to a degeneration of the race,* but it is more probably simply the self-assertion of those impurities which are best suited to the new environment. The problem of the introduction of exotic races, consequently assumes a new aspect. Viewed in this light, the larger the original importation of seed, the less would appear to be the chance of successful introduction owing to the greater difficulty in the control of this process of displacement of one form by another. If acclimatization on a practical basis be possible, it requires, for the development of the conditions most favourable to success, to be carried out in a manner which admits of the detailed work involved in the extraction, testing and multiplication, of the better components as single plant, or, at least, pure cultures. For this purpose a comparatively small importation and a comparatively small area is all that is at first necessary. Whether, under such conditions, it is possible to raise a race of exotic cotton suited to the conditions of Northern India can only be tested by experiment for on this matter the evidence afforded by the past lack of success is irrelevant. It is not desired here to re-awaken hopes which have so frequently been raised in

* Watt, Wild and Cultivated Cottons, p. 199.

the past only to lead to disappointment; there is sufficient scope for the improvement of the races of the truly Indian cottons to render this the most promising line of work as far as Northern India is concerned. If, however, the causes for lack of success in the past are those here indicated, it follows that the possibility, or the reverse, of acclimatising such forms as the higher grades of American or Egyptian cottons remains yet to be proved.*

Since the above notes were submitted to the Press a paper dealing with the Natural Crossing in Cotton and published in the American Breeders' Magazine† has been received. In this paper the author describes certain experiments and observations which he has made with the direct object of ascertaining the amount of cross-fertilisation taking place. He concludes that in N. Georgia at least 20 per cent. with strong probabilities of 40 per cent. of the blossoms are crossed.

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* For a further account of this phenomenon of 'degeneration,' the reader is referred to Section C of Studies of Egyptian Cotton, containing a biological sketch of the cotton crop of Egypt by Balls, in the Year-book, Khedivial Agricultural Society, 1909.

† Allard, Amer. Breeders' Mag. 1, 1910, 4, p. 247.

APPENDIX.

For ready reference a key to the types here referred to by numbers is attached. (Cf. Proc. Royal Socy. B, Vol. 83, 1911).

Monopodial types.

(*a*) foliage green

† Plant glabrous or nearly so, branches ascending, bracteoles triangular with margin entire or dentate, leaf-factor < 2

Type 1. *G. obtusifolium Roxb.*

†† Plant pubescent, branches spreading, bracteoles deeply auriculate or reniform with margin deeply serrate, leaf-factor < 2

Type 2. *G. herbaceum Linn.*

(*b*) foliage red

Plant differing from Type 1 in the colour of the foliage and petals and the leaf-factor which is > 3.

Type 3. *G. arboreum Linn.*

Sympodial types.

(*a*) foliage green

(1) leaf-factor < 2

† leaf commonly with 3 lobes, bracteoles small closely enveloping bud and fruit, petals yellow.

Type 4. *G. indicum Lamk.*

†† leaf lobes 5-7, petals yellow

Type 5.

††† leaf lobes 5-7, petals white

Types 6 & 7.

(2) leaf-factor > 3

† leaf lobes 5-7, petals yellow

Type 8.

†† leaf lobes 5-7, petals white

Type 9.

Types (5)—(9) are included in the *G. neglectum* and *G. roseum* of Todaro.

††† bracteoles large and continuing to grow during development of the boll which is large and many seeded, petals pale yellow.

Type 10. *G. cernuum Tod.*

(*b*) foliage red

leaf-factor > 3, petals red on white

Type 11. *G. sanguineum Hassk. var-minor* of Gammie.

TABLE I.

	Type 3.				Type 9.				Type 6*a*.				Type 6*b*.					
	Selfed.		Crossed.		Selfed.		Crossed.		Selfed.		Crossed.		Selfed.		Crossed.			
	No.	Set.	No.	Set.	No.	Set.	No.	Set.	No.	Set.	No.	Set.	No.	Set.	No.		Set.	
1906	17	8	...	..	14	7	...	...	10	6			20	11	...		...	
1907	20	3	6	2	21	9	...	...	22	11	.	..	20	10	...		...	
1908	...	...	...	...	10	0	7	3	18	9	..	...	1	0	16		9	
															Selfed. No.	Set.	Crossed. No.	Set.
1909	..	..	.	.	..	...	...	...	12	10	13	9	.	...	7	3	3	3
							32 selfed gave 123 seeds.		54 selfed gave 91 seeds.						10 selfed gave 69 seeds.			

	Type 9.		Type 6*b*.		
	Plants.	Seed.	Plants.	Seed.	
1910	40	211g	45	325g	Plants of each type under a single net.

Table II.

	F_1 1907.			F_2 1908.		
	Number.	Set.	%	Number.	Set.	%
Type 2 × Type 4	82	35	43	320	66	11
„ 2 × „ 8	152	59	39	..	...	...
„ 3 × „ 4	145	61	42	3666	1541	42
„ 3 × „ 9	124	62	50	1927	828	43

Table III.

(*a*) Parents ?					(*b*) Type 3 × Type 4 3·13 1·40				
F_1	Intermediate.				Intermediate. 2·27				
	< 2	> 2 < 3		> 3	< 2	> 2 < 3		> 3	
F^2	9	21		6	61	113		83	
Used as parents	4	6		1	..	..		..	
	< 2	< 2	> 2 < 3	> 3	< 2	< 2	> 2 < 3	> 3	> 3
F_2 ..	8	4	13	8	1	1222/(5)*	784	1602	791	1273/(6)*

* Exceptions in which the limit is not observed.

TABLE IV.

Parent Character.	Number.	Offspring.	
		Pure.	Impure.
Flower, yellow	34	951	..
Flower, white	20	486	..
	6	173	7

Parent Character.	Number.	Offspring.		
		< 2	> 2 < 3	> 3
Leaf-factor < 2	16	227	..	..
	3	36	8	..
Do. > 2 < 3	10	161	47	160
Do. > 3	22	..	..	777
	9		20	211

TABLE V.

		EARLY SERIES.				LATE SERIES.			
		PARENTS.	OFFSPRING.			PARENTS.	OFFSPRING.		
			Pure.	Impure.	% Impurity.		Pure.	Impure.	% Impurity.
			Lamina.	Veins.			Lamina.	Veins.	
Type 3 × Type 4	Red to Lamina.	5	49	...	...	15	212	...	...
		15	282	60	18·3	1	22	1	0·4
			Colourless.	Veins.			Colourless.	Veins.	
	Foliage, colourless.	7	91	...	..	4	89	...	...
		16	282	44	11·8	5	135	10	4·4
			Lamina.	Veins.			Lamina.	Veins.	
Type 3 × Type 9	Red to Lamina.	13	124	...	...	8	126	..	...
		12	163	35	12·2	13	333	34	7·4
			Colourless.	Veins.			Colourless.	Veins.	
	Foliage, colourless.	14	253	...	...	33	1089	...	
		7	171	27	6·3	12	540	42	2·5
			Flower, white.	Flower, yellow.			Flower, white.	Flower, yellow.	
	Flower, white.	7	98	...	...	5	122	...	...
		2	15	3	2·6	5	271	18	4·6

TABLE VI.

Distance.	Plants.	Offspring. Pure.	Offspring. Impure.	% Impurity.
2 ft. 6 in.	20	217	...	
	36	649	133	13
3 ft.	8	108	...	
	5	120	18	7
3 ft. 9 in.	3	89	8	8
5 ft. 9 in.	1	6	1	14*
6 ft.	1	12	...	
	1	36	6	12*
6 ft. 6 in.	1	5	...	
7 ft.	1	11	2	*
8 ft. 6 in.	1	40	...	
9 ft.	1	4	1	*
10 ft.	1	40	...	
	1	34	2	
13 ft.	1	35	1	
17 ft. 6 in.	1	21	...	
20 ft.	1	65	...	
33 ft.	1	68	...	
50 ft.	1	18	...	

Diagram 1—

.	.	r	R	y
			(1)	
.	y	r	y	R
			(2)	
.	.	R	R	r
		(3)		
.	r	R	S	R
		(4)	(5)	
R	y	r	S	.
r	R	r	y	y
	(6)			
s	s	r	R	R
			(7)	
.	.	r	S	y
			(8)	
.	.	r	w	w

(1) 1 cross in 25 plants .. nearest possible cross 2 ft. 6 in.
(2) 3 crosses in 25 plants .. ,, ,, 2 ft. 6 in.
(3) 6 crosses in 30 plants .. ,, ,, 2 ft. 6 in.
(4) no cross effected in 9 plants .. ,, ,, 2 ft. 6 in.
(5) no cross effected in 13 plants .. ,, ,, 2 ft. 6 in.

* Intermediate plants dead.

(6)	no cross effected in 6 plants ..	nearest possible cross	2 ft. 6 in.
(7)	2 crosses in 4 plants ..	,, ,,	2 ft. 6 in.
(8)	no cross effected in 17 plants ..	,, ,,	2 ft. 6 in.

Throughout these diagrams—

R = foliage and flower full red.
r = foliage with red to veins, flower red on yellow.
S = foliage full red, flower red on white.
s = foliage with red to veins, flowers red on white.
y = foliage green, flower yellow.
w = foliage green, flower white.
. = vacancy.

Diagram 2—

.	.	y	.	w
w	y	.	.	.
.	.	S	.	S
.	S	S	s	s
.	.	(S)	.	.
S	.	S	.	w
.	S	S	.	.
S	S	S	s	s
S	.	S	.	.
.	R	.	.	R

1 cross by pure red ; nearest possible cross .. .. 13 ft.
2 crosses by yellow ,, ,, ... 10 ft.
1 cross by white ,, ,, ... 6 ft. 6 in.

Diagram 3—

S	S	s
S	(w)	s
	channel 2 ft.	
S	w	S
R	r	r

Cross with red not effected ; nearest possible cross 2 ft. 6 in.
2 crosses with yellow in 13 plants ; nearest possible cross 7 ft.

Diagram 4—

.	r	r	R	.
r	.	y	y	.
		(1)		
y	.	y	.	r
		(2)		
.	.	.	.	.
.	.	.	.	.
.	r	r	.	.

(1) 6 crosses in 35 plants ; nearest possible cross .. 2 ft. 6 in.
(2) 6 crosses in 42 plants „ „ .. 6 ft.

Intermediate plants dead.